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MEMORANDUM REPORT NO. 1681

THE ZERO-YAW DRAG COEFFICIENT FOR PROJECTILE, 8-INCH: HE, M106

by

Elizabeth R. Dickinson

September 1965

U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1681

SEPTEMBER 1965

THE ZERO-YAW DRAG COEFFICIENT FOR PROJECTILE, 8-INCH: HE, M106

Elizabeth R. Dickinson

Computing Laboratory

RDT & E Project No. 1P523801A287

ABERDEEN PROVING GROUND, MARYLAND

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ERDickinson/vc
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September 1965

THE ZERO-YAW DRAG COEFFICIENT FOR PROJECTILE, 8-INCH: HE, M106

ABSTRACT

This report presents an analytical fit of experimentally determined drag coefficients for the howitzer shell designated as Projectile, 8-Inch: HE, M106. Both a tabular and a graphical representation of the fitted coefficients are included.

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INTRODUCTION

In 1941, the first firing table for the 8-inch M106 howitzer projectile was published. This firing table (FT 8-J-1) was based on data, obtained from firings in 1940, reduced with the G_5 drag coefficient. In 1958, FT 8-J-2 was published. The data for this table were based on the 1940 firings plus some supplementary firings conducted in 1955. All of the data (1940 and 1955) were reduced, on the EDVAC and the ORDVAC, using a drag coefficient based on radio doppler measurements [1]. In 1960, standard firing table format was changed; thus it became necessary to rework the data of FT 8-J-2 and publish it as FT 8-J-3.

Since 1960 and the publication of FT 8-J-3, firing table format has again changed: all tabulations are now in terms of meters per second, and a table of fuze setting factors has been added. Also, more probable error data for this projectile have become available. Since the advent of BRLESC, computing techniques for the production of firing tables have become more sophisticated. Hence the Artillery requested that a new 8-inch firing table be published (FT 8-J-4).

All of the data available since 1940 were to be reanalysed by modern methods. In addition, when the new self-propelled 8-inch howitzer became available, firings were conducted (1962-1963) to determine whether or not the same firing table could be used for firing the M106 projectile from both this vehicle and the towed vehicle. Reduction of the data from these firings showed a wide variation in ballistic coefficient for rounds fired in the low zones (charges 1, 2 and 3). Hence it was decided to investigate the drag coefficient of the M106 projectile at subsonic velocities.

DRAG COEFFICIENT

The experimental data used for determining the Mach number-drag coefficient relationship for the 8-inch M106 projectile (Fig. 1) were obtained from firings conducted by the Exterior Ballistics Laboratory in the large free flight range [2]. These data were fitted analytically in the Computing Laboratory.

It was assumed that in the subsonic region, the drag coefficient is independent of Mach number. Hence, the zero-yaw drag coefficient, C_{D_o}, was determined by the following relationship.

$$C_{D_o} = C_D - C_{D_\delta} \overline{\delta^2}$$

where C_{D_o} = zero-yaw drag coefficient

C_{D_δ} = yaw drag coefficient (deg^{-2})

$\overline{\delta^2}$ = mean squared yaw (deg^2)

It became immediately apparent that in this subsonic region there existed two distinct levels of drag. C_{D_o} for each level was determined independently (Fig. 2), resulting in slightly different yaw-drag coefficients for each level.

High level: $C_{D_o} = .1227$; $C_{D_\delta} = .000911/deg^2$

Low level: $C_{D_o} = .1054$; $C_{D_\delta} = .001123/deg^2$

Examination of the photographic plates from the range gave a possible explanation of this phenomenon. This examination showed that the flow going over the rotating bands of the high drag rounds differed from that going over the low drag rounds. Because the resolution on the plates is not adequate for detailed study, it is not possible to pinpoint the cause of this difference in flow. It might be due to a difference in the depth of body undercut, to a malformation of the rotating band or to a combination of both.

The wake patterns of two rounds, one typical of the high drag rounds and one typical of the low drag rounds, were measured (Table I). Whatever the cause of the difference in flow over the rotating bands, it resulted in a decrease in effectiveness of the boattail thus increasing base drag.

Although no definite explanation of the two levels of drag can be stated at this time, the fact of their existence does explain the variations in ballistic coefficient. Nevertheless, a two-level drag coefficient is not practical for the purpose of producing a firing table. The artilleryman in the field does not know whether he is about to fire a high drag round or a low drag round. Therefore all of the rounds below M = .84 were grouped together with the following results.

$$C_{D_o} = .11098065; \quad C_{D_\delta} = .0010386852/\text{deg}^2$$

The use of this combined drag coefficient in the computation of the firing table could result in range errors. The greatest errors would be in zones 1 and 2, where the entire flight of the projectile is in the subsonic region. In order to determine the magnitude of the range errors in these two zones, trajectories were computed using the high, low and combined subsonic drag coefficients. At the maximum ranges (where maximum error would be encountered) there is a possibility of an error in range of +58, -28 meters in zone 1; +79, -39 meters in zone 2.

Because the new subsonic drag coefficients differed appreciably from the subsonic drag coefficient determined by the doppler measurements [1] (Fig. 2), it was deemed advisable to fire additional rounds in the free flight range to check the drag coefficient in the transonic and supersonic regions. The data from these firings (Table II), corrected for yaw [C_{D_δ} (M > .84) = .001017] and fitted analytically, resulted in the Mach number-drag coefficient curve shown in figure 3. Although the curve differs significantly from the old one in the subsonic region, it is in fair agreement with the old curve throughout the remaining range of Mach numbers (Fig. 4).

Following are the expressions for the Mach number-drag coefficient relationship being used in the production of the firing table, FT 8-J-4. Subsonically, the drag is a constant; through a portion of the transonic rise, the drag coefficient is a linear function of Mach number. The remainder of the experimental data was fitted by several polynomial functions of Mach number, with the requirement that C_{D_o} and its first derivative should be equal at the points of juncture. The tabulated values are given in Table III, the graphical representation in figure 3.

Interval	C_{D_o}
$0.0 \le M \le .860$	$.11098065$
$.860 \le M \le .95197594$	$10.094889 - 23.218392M + 13.499065M^2$
$.95197594 \le M \le .96784380$	$-2.1387491 + 2.4831784M$
$.96784380 \le M \le 1.10$	$-11.547651 + 21.926195M - 10.044501M^2$
$1.10 \le M \le 2.00$	$.67467570 - .29621652M + .056594850M^2$

TABLE I

WAKE CONVERGENCE PATTERNS

Calibers behind base	Diameter of wake/Diameter of base	
	Low drag round	High drag round
.5	.96	
1.0	.90	1.12
2.0	.72	1.06
2.5	.60	
3.0		1.00

TABLE II

EXPERIMENTAL DATA FROM FREE FLIGHT MEASUREMENTS

Round No.	M	C_D	$\overline{\delta^2}$ (deg^2)
7009	.706	.1094	3.6
6987	.719	.1644	52.6
6879	.743	.1220	.5
6986	.789	.1049	1.1
6876	.793	.1116	2.5
6877	.830	.1071	3.1
7007	.830	.1285	5.5
6985	.839	.2052	90.2
6983	.868	.1270	.4
6880	.869	.1284	.4
6878	.870	.1172	.6
6989	.906	.1514	.4
7008	.910	.1453	1.7
6875	.915	.1566	3.1
6990	.934	.1795	3.3
7003	.985	.3282	3.9
6994	1.003	.3403	1.0
7004	1.068	.4157	5.0
7006	1.180	.4104	5.1
7323	1.284	.3894	.5
7322	1.388	.3760	.4
7005	1.421	.3632	1.1
7324	1.588	.3465	.4
7325	1.598	.3480	1.9
7002	1.695	.3413	2.6
7326	1.926	.3106	.5
7327	1.941	.3168	1.1

TABLE III

TABLE OF DRAG COEFFICIENTS

M	C_{Do}	M	C_{Do}	M	C_{Do}
0.855	.1110	0.895	.1275	0.935	.1869
0.856	.1110	0.896	.1285	0.936	.1890
0.857	.1110	0.897	.1295	0.937	.1910
0.858	.1110	0.898	.1305	0.938	.1931
0.859	.1110	0.899	.1315	0.939	.1952
0.860	.1110	0.900	.1326	0.940	.1974
0.861	.1110	0.901	.1337	0.941	.1995
0.862	.1110	0.902	.1348	0.942	.2017
0.863	.1111	0.903	.1359	0.943	.2040
0.864	.1112	0.904	.1371	0.944	.2062
0.865	.1113	0.905	.1383	0.945	.2085
0.866	.1115	0.906	.1395	0.946	.2108
0.867	.1116	0.907	.1408	0.947	.2132
0.868	.1118	0.908	.1421	0.948	.2155
0.869	.1121	0.909	.1434	0.949	.2179
0.870	.1123	0.910	.1447	0.950	.2203
0.871	.1126	0.911	.1461	0.951	.2228
0.872	.1129	0.912	.1475	0.952	.2252
0.873	.1133	0.913	.1489	0.953	.2277
0.874	.1136	0.914	.1503	0.954	.2302
0.875	.1140	0.915	.1518	0.955	.2327
0.876	.1144	0.916	.1533	0.956	.2352
0.877	.1149	0.917	.1548	0.957	.2377
0.878	.1154	0.918	.1564	0.958	.2401
0.879	.1159	0.919	.1580	0.959	.2426
0.880	.1164	0.920	.1596	0.960	.2451
0.881	.1169	0.921	.1612	0.961	.2476
0.882	.1175	0.922	.1629	0.962	.2501
0.883	.1181	0.923	.1646	0.963	.2526
0.884	.1108	0.924	.1663	0.964	.2550
0.885	.1194	0.925	.1680	0.965	.2575
0.886	.1201	0.926	.1698	0.966	.2600
0.887	.1208	0.927	.1716	0.967	.2625
0.888	.1216	0.928	.1734	0.968	.2650
0.889	.1223	0.929	.1752	0.969	.2674
0.890	.1231	0.930	.1771	0.970	.2699
0.891	.1240	0.931	.1790	0.971	.2723
0.892	.1248	0.932	.1810	0.972	.2747
0.893	.1257	0.933	.1829	0.973	.2771
0.894	.1266	0.934	.1849	0.974	.2795
0.895	.1275	0.935	.1869	0.975	.2818

TABLE OF DRAG COEFFICIENTS

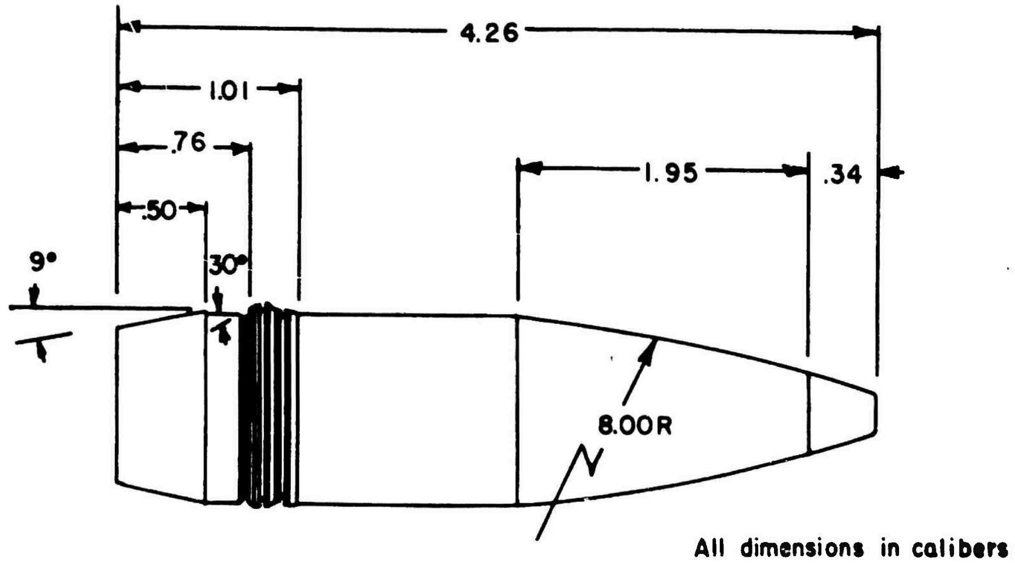
M	C_{Do}	M	C_{Do}	M	C_{Do}
0.975	.2818	1.015	.3593	1.055	.4047
0.976	.2842	1.016	.3609	1.056	.4054
0.977	.2865	1.017	.3624	1.057	.4061
0.978	.2888	1.018	.3639	1.058	.4068
0.979	.2910	1.019	.3653	1.059	.4075
0.980	.2933	1.020	.3668	1.060	.4081
0.981	.2955	1.021	.3682	1.061	.4087
0.982	.2977	1.022	.3696	1.062	.4093
0.983	.2999	1.023	.3710	1.063	.4099
0.984	.3021	1.024	.3723	1.064	.4105
0.985	.3042	1.025	.3737	1.065	.4110
0.986	.3064	1.026	.3750	1.066	.4115
0.987	.3085	1.027	.3763	1.067	.4120
0.988	.3106	1.028	.3776	1.068	.4125
0.989	.3126	1.029	.3789	1.069	.4130
0.990	.3147	1.030	.3801	1.070	.4134
0.991	.3167	1.031	.3813	1.071	.4138
0.992	.3187	1.032	.3825	1.072	.4143
0.993	.3207	1.033	.3837	1.073	.4146
0.994	.3227	1.034	.3849	1.074	.4150
0.995	.3246	1.035	.3860	1.075	.4153
0.996	.3265	1.036	.3872	1.076	.4157
0.997	.3284	1.037	.3883	1.077	.4160
0.998	.3303	1.038	.3894	1.078	.4162
0.999	.3322	1.039	.3904	1.079	.4165
1.000	.3340	1.040	.3915	1.080	.4167
1.001	.3359	1.041	.3925	1.081	.4170
1.002	.3377	1.042	.3935	1.082	.4172
1.003	.3395	1.043	.3945	1.083	.4173
1.004	.3412	1.044	.3954	1.084	.4175
1.005	.3430	1.045	.3964	1.085	.4176
1.006	.3447	1.046	.3973	1.086	.4178
1.007	.3464	1.047	.3982	1.087	.4179
1.008	.3481	1.048	.3991	1.088	.4179
1.009	.3498	1.049	.3999	1.089	.4180
1.010	.3514	1.050	.4008	1.090	.4180
1.011	.3530	1.051	.4016	1.091	.4180
1.012	.3546	1.052	.4024	1.092	.4180
1.013	.3562	1.053	.4032	1.093	.4180
1.014	.3578	1.054	.4040	1.094	.4180
1.015	.3593	1.055	.4047	1.095	.4179

TABLE OF DRAG COEFFICIENTS

M	C_{Do}	M	C_{Do}	M	C_{Do}
1.095	.4179	1.135	.4114	1.175	.4048
1.096	.4178	1.136	.4112	1.176	.4046
1.097	.4177	1.137	.4110	1.177	.4044
1.098	.4176	1.138	.4109	1.178	.4043
1.099	.4175	1.139	.4107	1.179	.4041
1.100	.4173	1.140	.4105	1.180	.4039
1.101	.4171	1.141	.4104	1.181	.4038
1.102	.4170	1.142	.4102	1.182	.4036
1.103	.4168	1.143	.4100	1.183	.4035
1.104	.4166	1.144	.4099	1.184	.4033
1.105	.4165	1.145	.4097	1.185	.4031
1.106	.4163	1.146	.4095	1.186	.4030
1.107	.4161	1.147	.4094	1.187	.4028
1.108	.4159	1.148	.4092	1.188	.4026
1.109	.4158	1.149	.4090	1.189	.4025
1.110	.4156	1.150	.4089	1.190	.4023
1.111	.4154	1.151	.4087	1.191	.4022
1.112	.4153	1.152	.4085	1.192	.4020
1.113	.4151	1.153	.4084	1.193	.4018
1.114	.4149	1.154	.4082	1.194	.4017
1.115	.4148	1.155	.4080	1.195	.4015
1.116	.4146	1.156	.4079	1.196	.4014
1.117	.4144	1.157	.4077	1.197	.4012
1.118	.4142	1.158	.4075	1.198	.4010
1.119	.4141	1.159	.4074	1.199	.4009
1.120	.4139	1.160	.4072	1.200	.4007
1.121	.4137	1.161	.4071	1.210	.3991
1.122	.4136	1.162	.4069	1.220	.3975
1.123	.4134	1.163	.4067	1.230	.3960
1.124	.4132	1.164	.4066	1.240	.3944
1.125	.4131	1.165	.4064	1.250	.3928
1.126	.4129	1.166	.4062	1.260	.3913
1.127	.4127	1.167	.4061	1.270	.3898
1.128	.4126	1.168	.4059	1.280	.3882
1.129	.4124	1.169	.4057	1.290	.3867
1.130	.4122	1.170	.4056	1.300	.3852
1.131	.4120	1.171	.4054	1.310	.3838
1.132	.4119	1.172	.4052	1.320	.3823
1.133	.4117	1.173	.4051	1.330	.3808
1.134	.4115	1.174	.4049	1.340	.3794
1.135	.4114	1.175	.4048	1.350	.3779

TABLE OF DRAG COEFFICIENTS

M	C_{Do}	M	C_{Do}
1.350	.3779	1.700	.3347
1.360	.3765	1.710	.3336
1.370	.3751	1.720	.3326
1.380	.3737	1.730	.3316
1.390	.3723	1.740	.3306
1.400	.3709	1.750	.3296
1.410	.3695	1.760	.3286
1.420	.3682	1.770	.3277
1.430	.3668	1.780	.3267
1.440	.3655	1.790	.3258
1.450	.3642	1.800	.3249
1.460	.3628	1.810	.3239
1.470	.3615	1.820	.3230
1.480	.3602	1.830	.3221
1.490	.3590	1.840	.3212
1.500	.3577	1.850	.3204
1.510	.3564	1.860	.3195
1.520	.3552	1.870	.3187
1.530	.3539	1.880	.3178
1.540	.3527	1.890	.3170
1.550	.3515	1.900	.3162
1.560	.3503	1.910	.3154
1.570	.3491	1.920	.3146
1.580	.3479	1.930	.3138
1.590	.3468	1.940	.3130
1.600	.3456	1.950	.3123
1.610	.3445	1.960	.3115
1.620	.3433	1.970	.3108
1.630	.3422	1.980	.3100
1.640	.3411	1.990	.3093
1.650	.3400	2.000	.3086
1.660	.3389		
1.670	.3378		
1.680	.3368		
1.690	.3357		
1.700	.3347		



Projectile , 8-INCH: HE, M 106
with Fuze, PD, M 51A5

Fig. 1

Two Levels of Drag
in
Subsonic Region

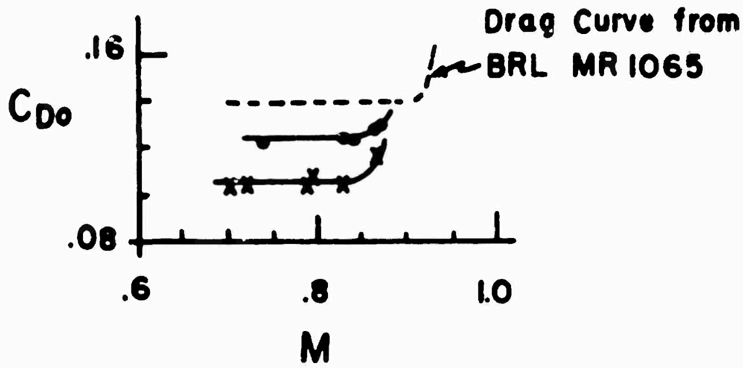


Fig. 2

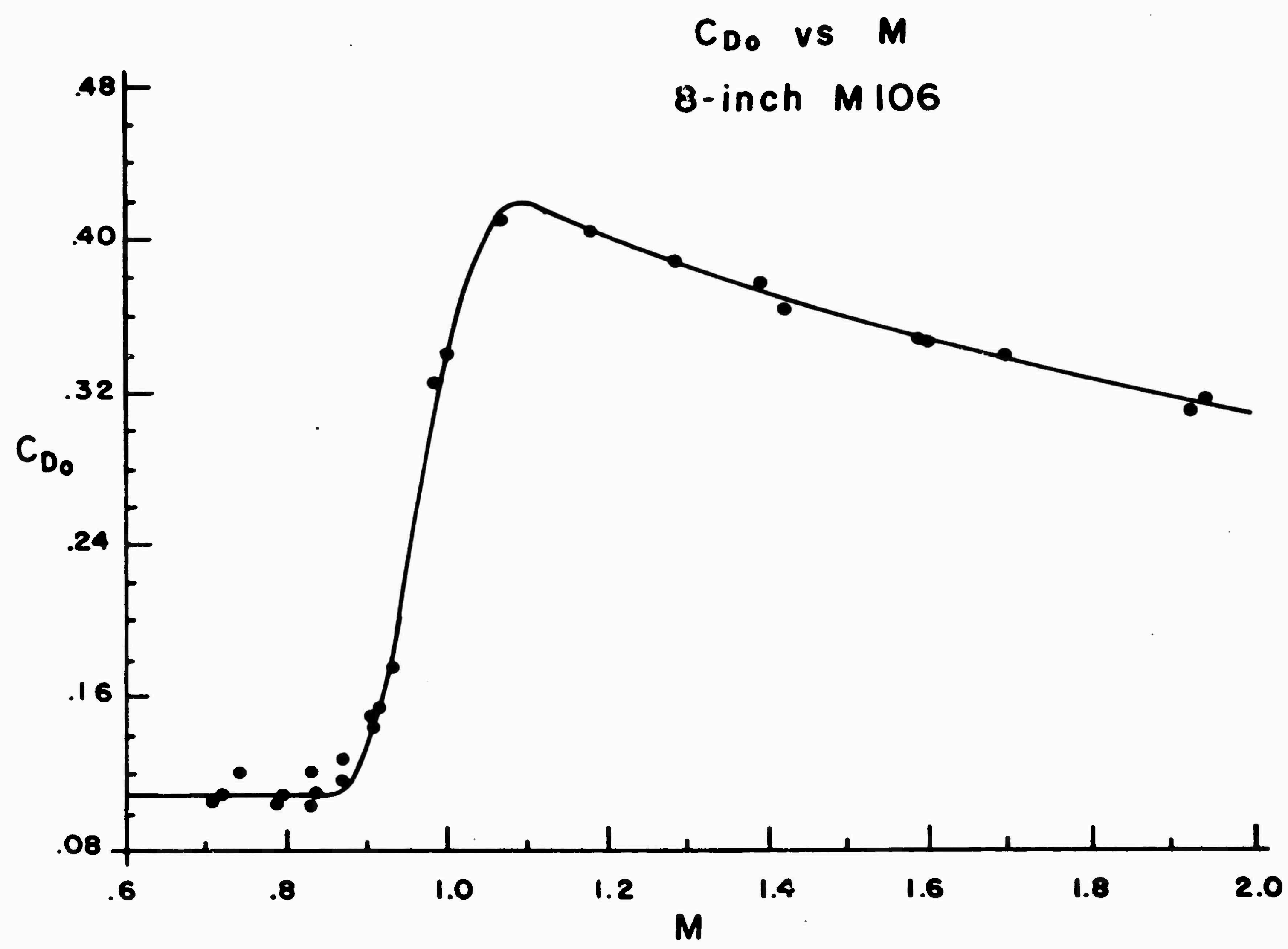


Fig. 3

C_{D_0} vs M

8-inch M106

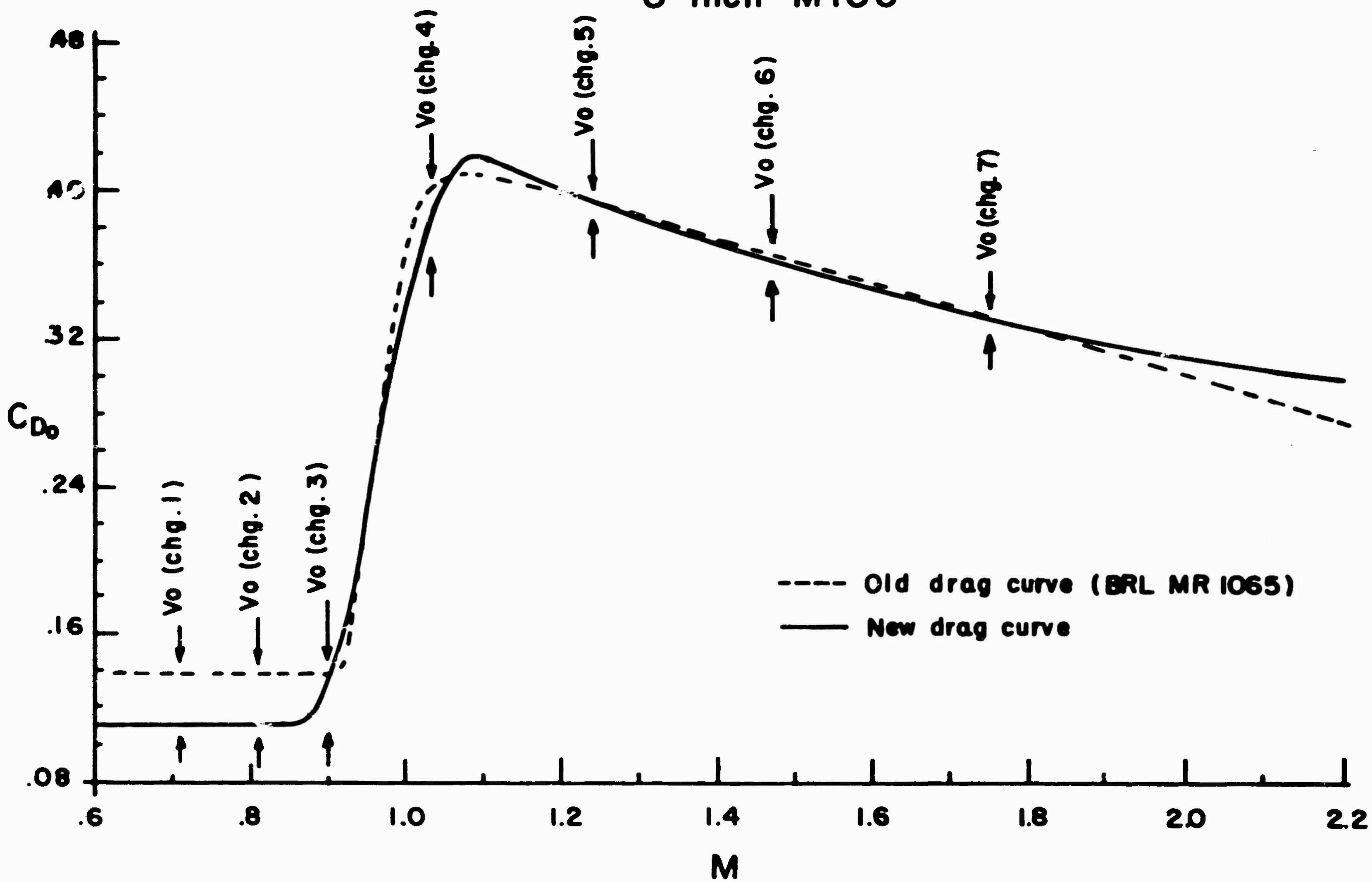


Fig. 4

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2. Walter K. Rogers, Jr. The Transonic Free Flight Range BRL R-1044, June 1958.

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13. ABSTRACT

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